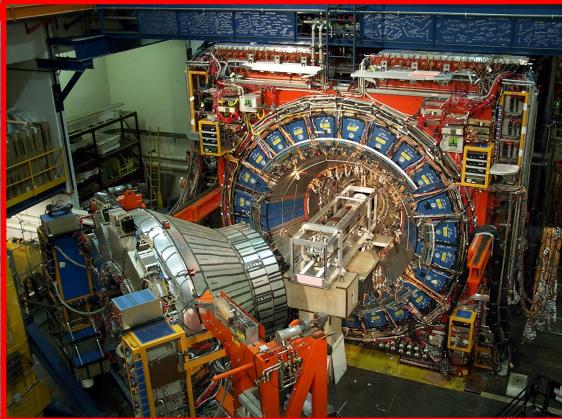


# Searches for the Supersymmetric Partner of the Bottom Quark



Carsten Rott, Purdue University  
for the CDF Collaboration

Tsukuba, Japan, 2004

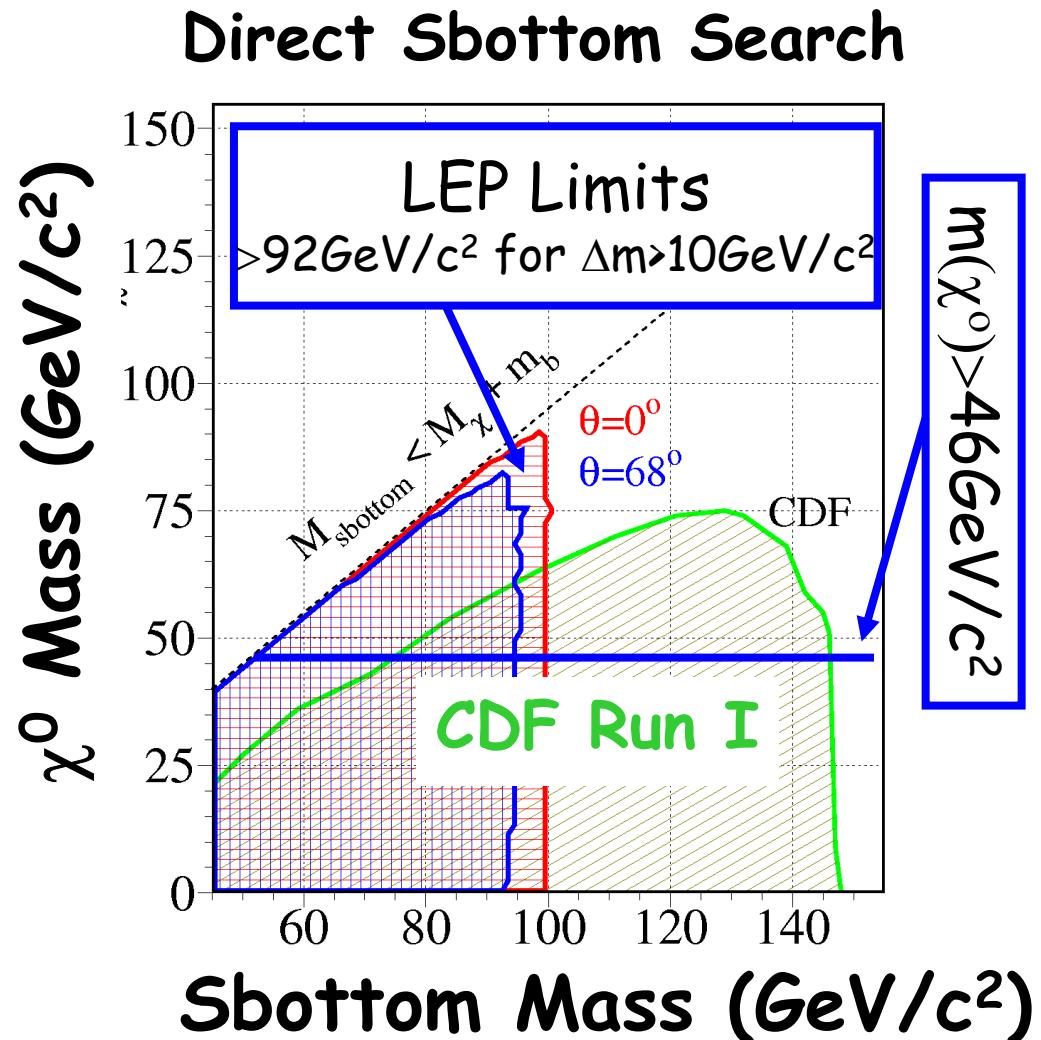
# Sbottom Searches

$$m_{\tilde{b}_{1,2}}^2 = \frac{1}{2} [m_{\tilde{b}_L}^2 + m_{\tilde{b}_R}^2 \mp \sqrt{(m_{\tilde{b}_L}^2 - m_{\tilde{b}_R}^2)^2 + 4m_b^2(A_b - \mu \tan \beta)^2}]$$

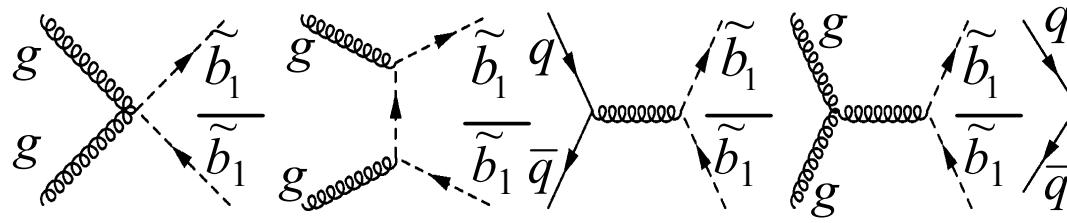
$\uparrow$   
Sbottom could be light due to large mass splitting between the eigenstates (large  $\tan\beta$ )

Assume:

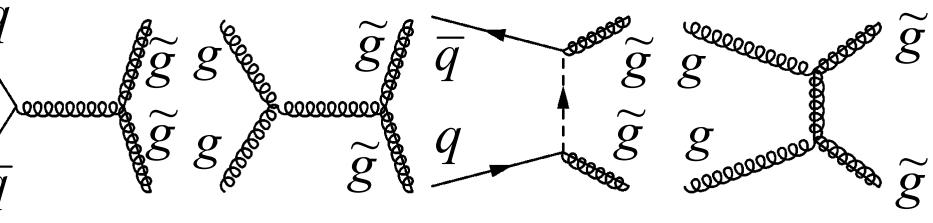
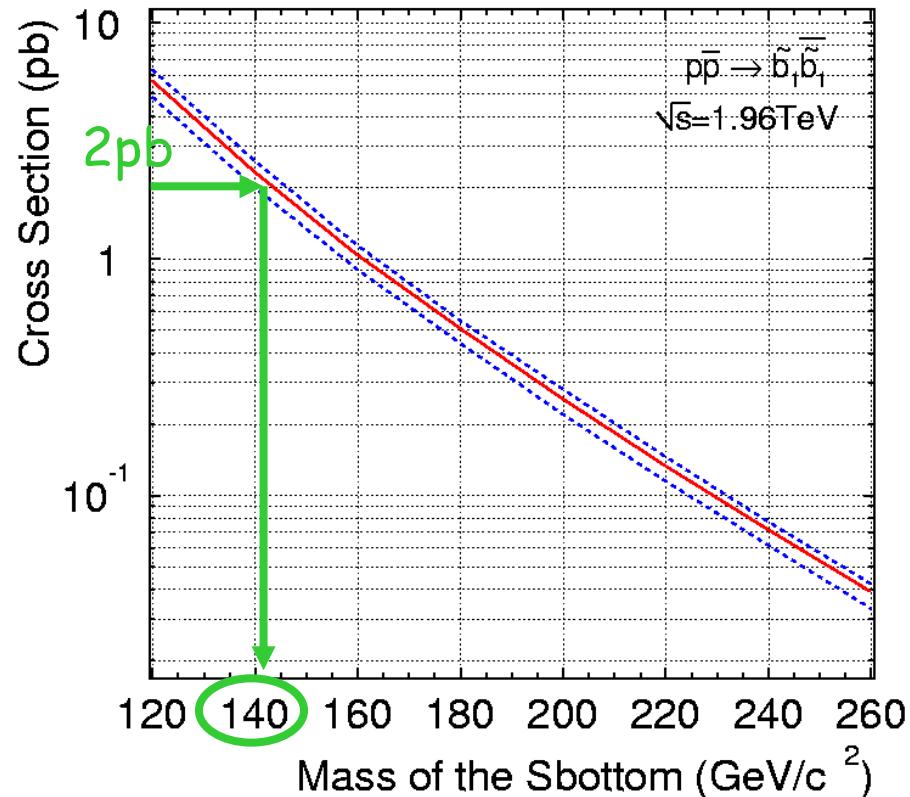
- $BR(\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0) = 100\%$
- R-parity conservation which leads to stable undetectable neutralino



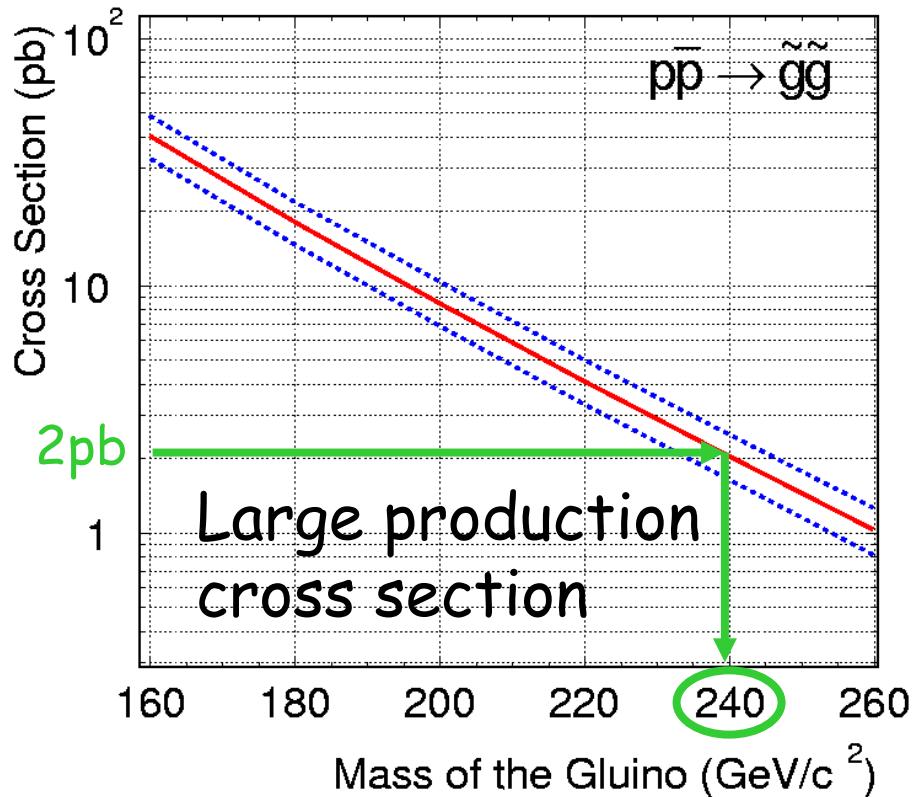
## Direct Sbottom production: Gluino-pair production:



— Prospino CTEQ5M,  $Q=m(\tilde{b})$   
 - - - Prospino CTEQ5M,  $Q=0.5m(\tilde{b}), 2m(\tilde{b})$

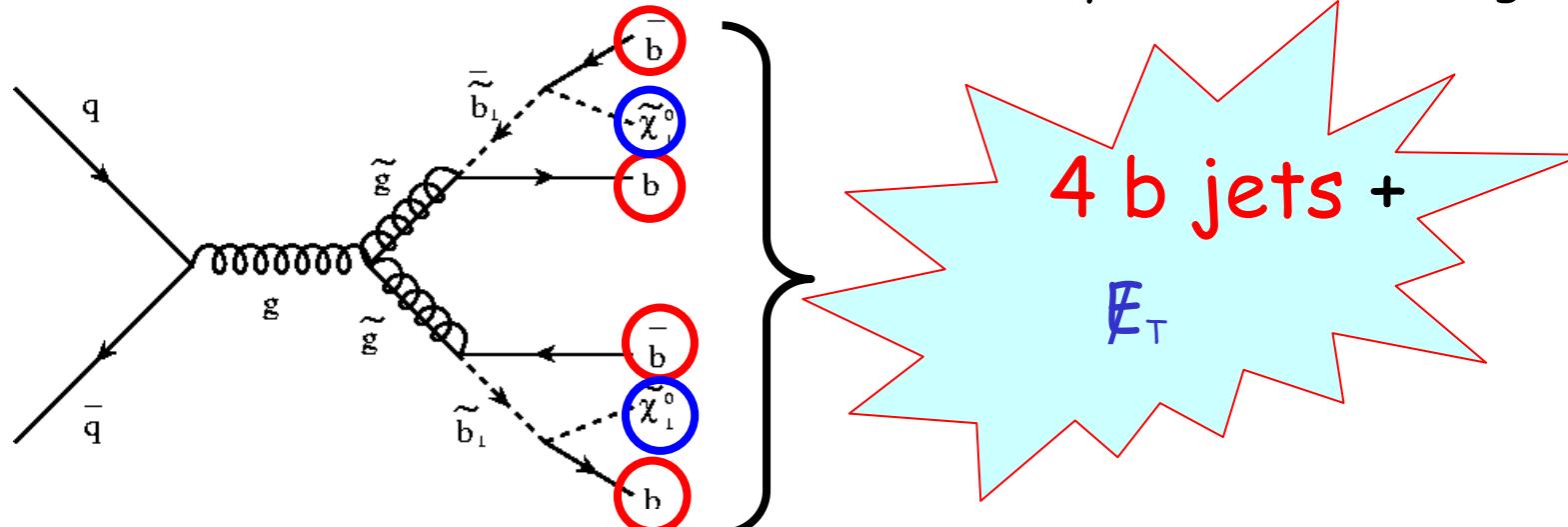


— Prospino CTEQ5M,  $Q=m(\tilde{g})$   
 - - - Prospino CTEQ5M,  $Q=0.5m(\tilde{g}), 2m(\tilde{g})$



Large production  
cross section

Sbottom quarks could be pair produced at the Tevatron or in a scenario where the gluino is heavier than the sbottom, through decays of gluinos. Consider here search for second case, it yields a richer signature



$$\tilde{g}\tilde{g} \rightarrow (b\tilde{b}_1)(b\tilde{b}_1) \rightarrow (bb\tilde{\chi}_1^0)(bb\tilde{\chi}_1^0)$$

Assume:

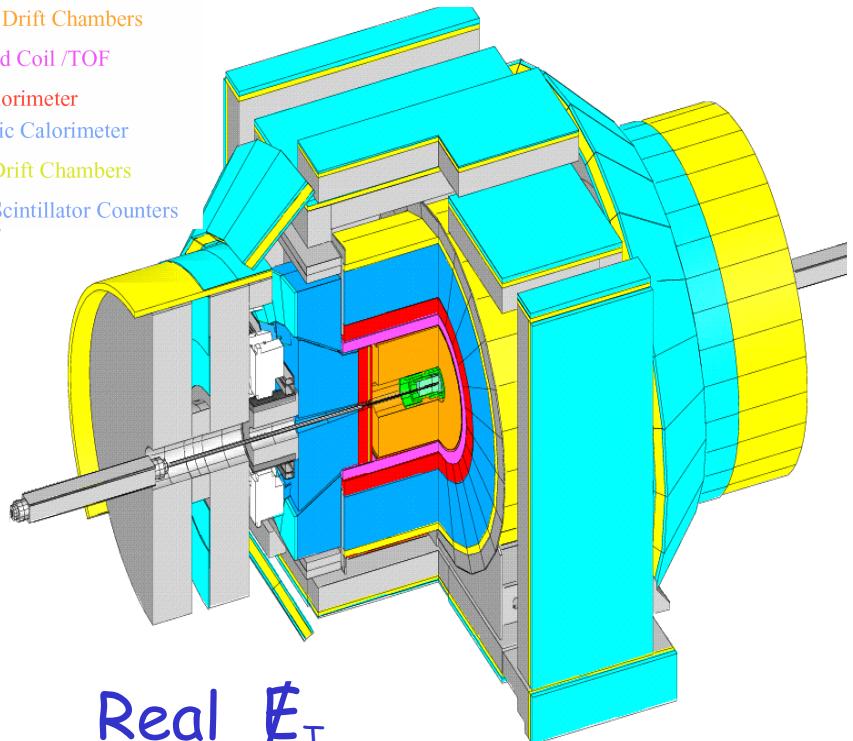
- $m_{\tilde{g}} > m_{\tilde{b}} > m_{\tilde{\chi}_1^0}$
- $m_t + m_{\tilde{\chi}_1^+} > m_{\tilde{b}_1} > m_{\tilde{\chi}_1^0}$
- $BR(\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0) = 100\%$

## Motivation

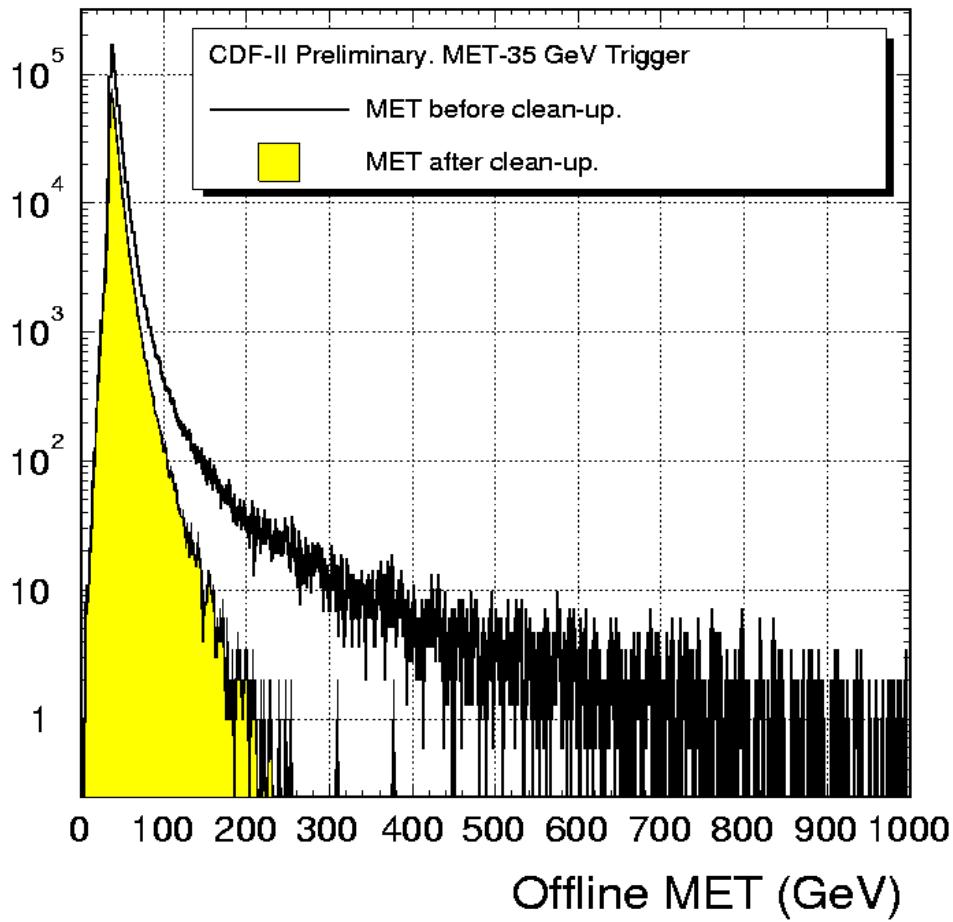
- Large cross section
- Very distinctive signature
- Accessible at Tevatron

$E_T$  caused by particles escaping detection or by detector mis-measurement

- [Green square] Silicon Tracking Detectors
- [Orange square] Central Drift Chambers
- [Magenta square] Solenoid Coil /TOF
- [Red square] EM Calorimeter
- [Blue square] Hadronic Calorimeter
- [Yellow-green square] Muon Drift Chambers
- [Light blue square] Muon Scintillator Counters



Events



Real  $E_T$   
from non-detectable

$$\nu, \tilde{\chi}_1^0, \dots$$

Fake  $E_T$

- limited detector coverage
- reconstruction
- cosmics

# B-Tagging at CDF

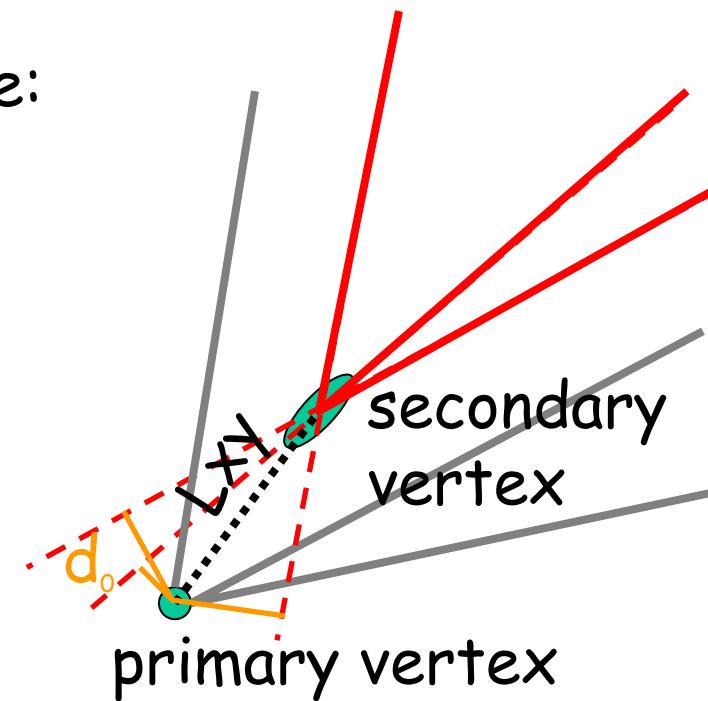
B hadrons fly macroscopic distance:  
 $\Delta L = c\tau \cdot \beta\gamma$  with  $c\tau \approx 450 \mu m$



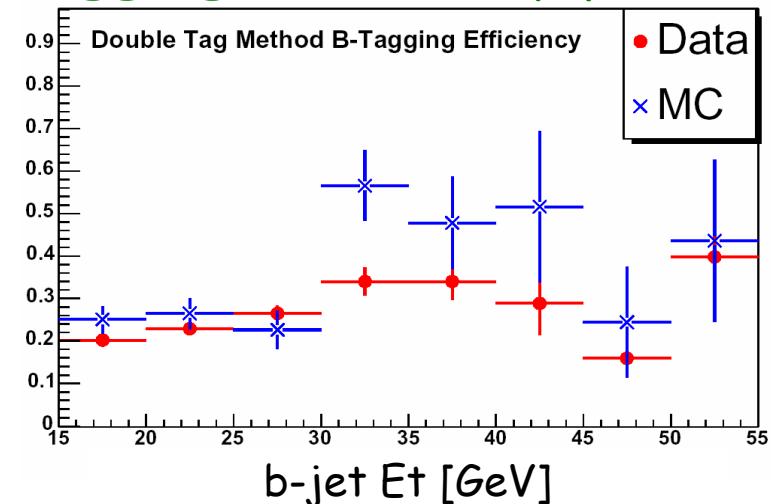
Can be detected using CDFs  
 Silicon Vertex Detector

b-jets are identified using a  
 secondary vertex tagging  
 algorithm.

Tracks with large impact  
 parameter  $d_o$  are selected and  
 a vertex fitting algorithm is  
 used to reconstruct a  
 displaced vertex.



B-tagging Efficiency per Jet



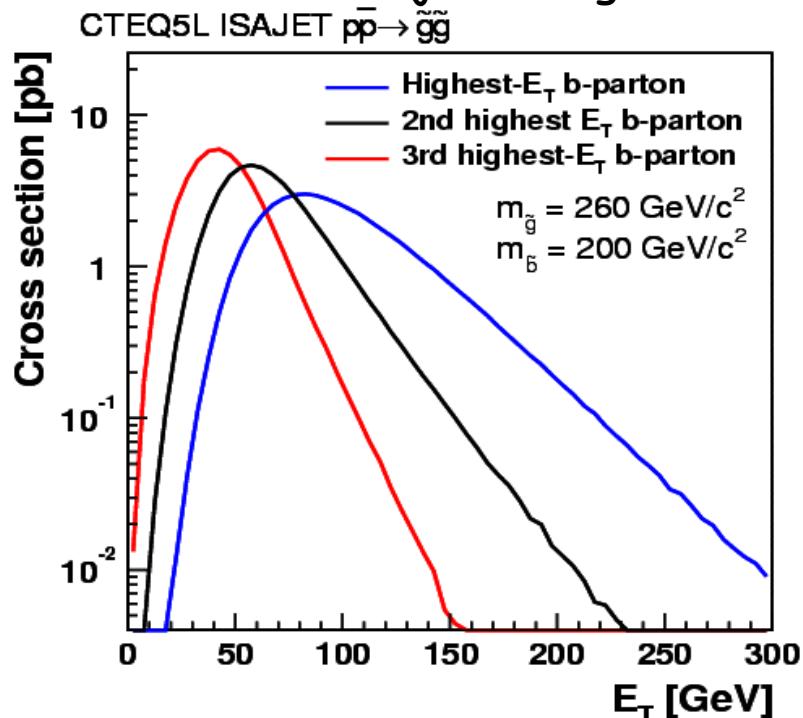
# Search Strategy

Event kinematics depend on the mass differences:

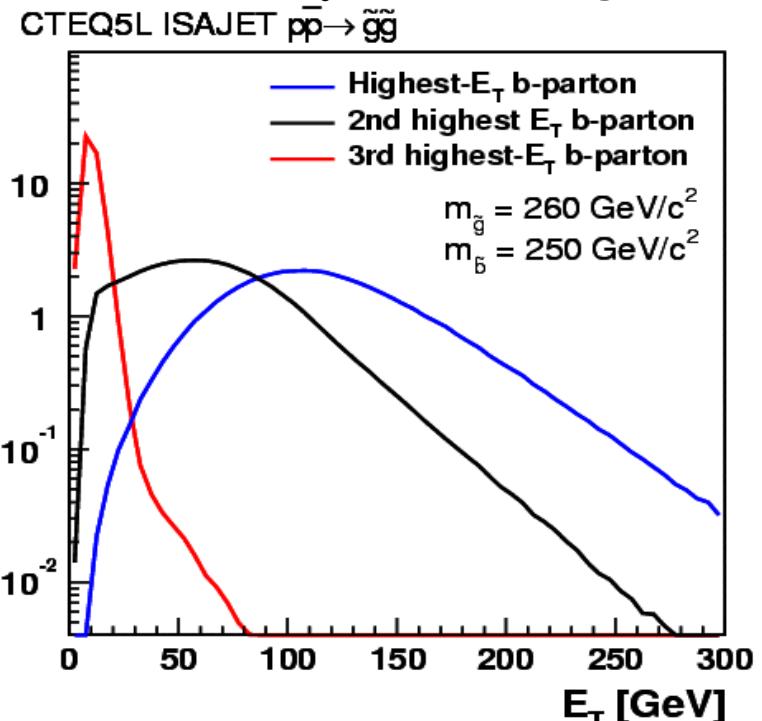
$$\Delta M = m(\text{gluino}) - m(\text{sbottom}) / \Delta m = m(\text{sbottom}) - m(\text{neutralino})$$

Assume fixed neutralino mass ( $60\text{GeV}/c^2$ ),  $\Delta m$  is large and consider different gluino/sbottom mass scenarios:

$\Delta M$  - large  $\rightarrow$  b from gluino energetic  
 $\chi$  boosted  $\rightarrow$  moderate  $E_T$   
 3<sup>rd</sup> b-jet energetic



$\Delta M$  - small  $\rightarrow$  b from sbottom decay energetic  
 $\chi$  not boosted  $\rightarrow$  larger  $E_T$   
 3<sup>rd</sup> b-jet non-energetic



Perform separate two analyses: Excl. single tagged / Inclusive double tagged

# Backgrounds

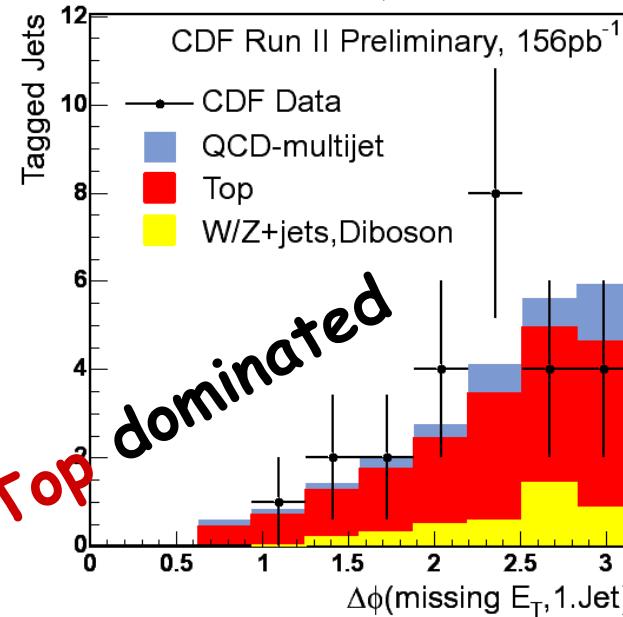
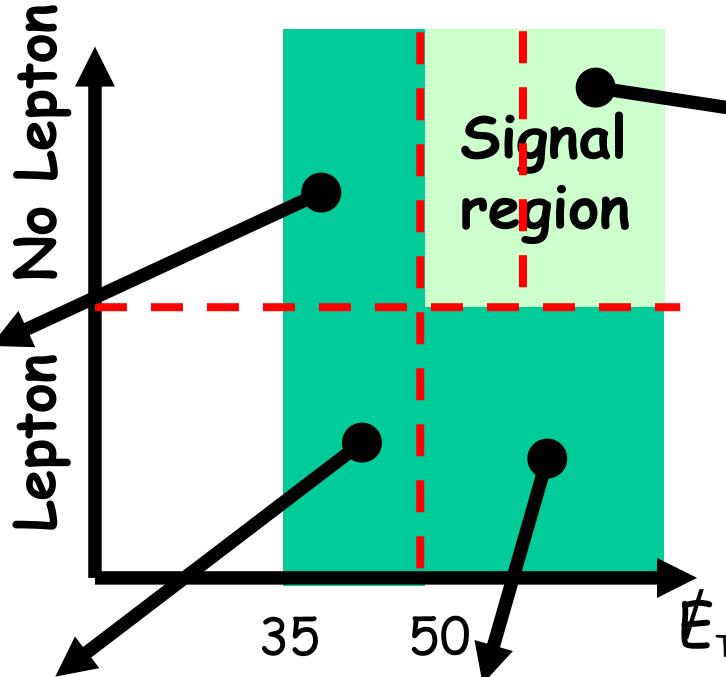
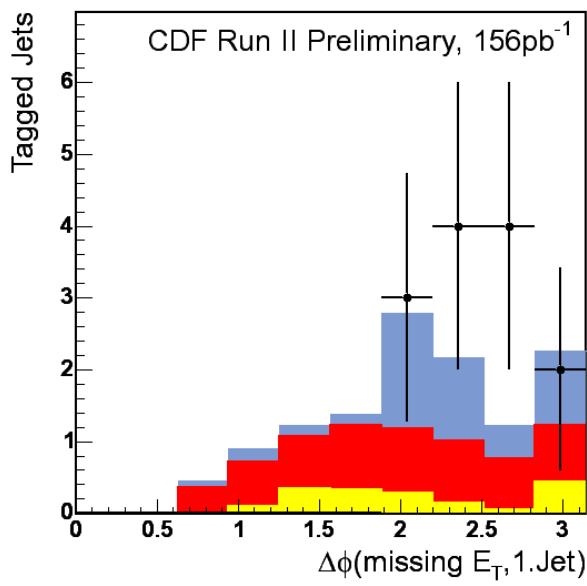
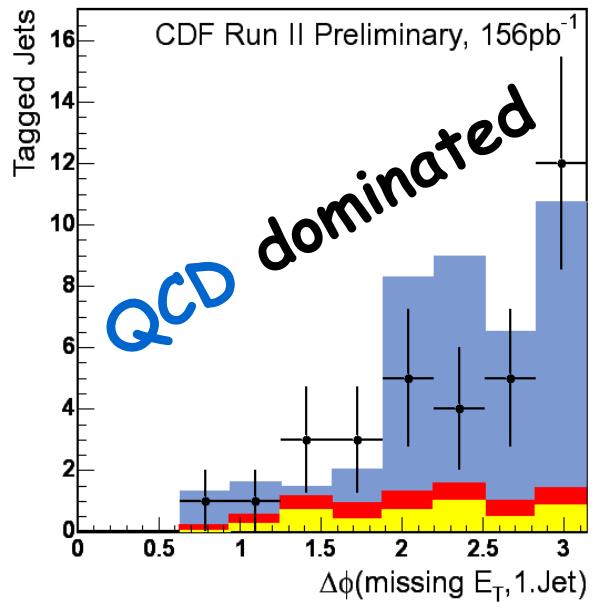
Backgrounds		Description	Reduction
<b>QCD</b> Fake tag rate parameterization from data + QCD HF MC	$b\bar{b}, c\bar{c},$ $q\bar{q}$	<ul style="list-style-type: none"> <li>• QCD heavy flavor production</li> <li>• mismeasured jet energy</li> <li>• semileptonic b-decay</li> <li>• <math>\sigma</math> large</li> </ul>	<ul style="list-style-type: none"> <li>• <math>\Delta\phi(\cancel{E}_T, \text{jets})</math> cuts</li> </ul>
<b>W/Z+jets</b> MC simulation	$W \rightarrow l\nu$ $Z \rightarrow ll, vv, b\bar{b}$	<ul style="list-style-type: none"> <li>• mismeasured jet energy</li> <li>• neutrinos</li> </ul>	<ul style="list-style-type: none"> <li>• isolated lepton veto</li> <li>• b-tag requirement</li> </ul>
<b>Diboson</b> MC simulation	$W \rightarrow l\nu$ $Z \rightarrow ll, vv, b\bar{b}$	<ul style="list-style-type: none"> <li>• neutrinos</li> <li>• <math>\sigma</math> small</li> </ul>	<ul style="list-style-type: none"> <li>• isolated lepton veto</li> <li>• b-tag requirement</li> </ul>
<b>Top</b> MC simulation	$t \rightarrow Wb$ $\downarrow l\nu$	<ul style="list-style-type: none"> <li>• b-jets</li> <li>• neutrinos</li> <li>• very similar signature !</li> </ul>	<ul style="list-style-type: none"> <li>• isolated lepton veto</li> </ul>

Event selection cuts

- Inclusive three jets  $\text{Pt} > 15 \text{ GeV}$   $|\eta| < 2$
- $\cancel{E}_T > 35 \text{ GeV}$
- $\Delta\phi(\cancel{E}_T, 1\text{-}3\text{jet}) > 40^\circ$
- Heavy flavor tags

Use  $\cancel{E}_T$ cut and lepton veto/requirement to define signal and control regions

# Signal and Control Regions



??

Define three control regions, based on  $E_T$  and lepton requirement to provide cross-check for background predictions.

# Control Regions

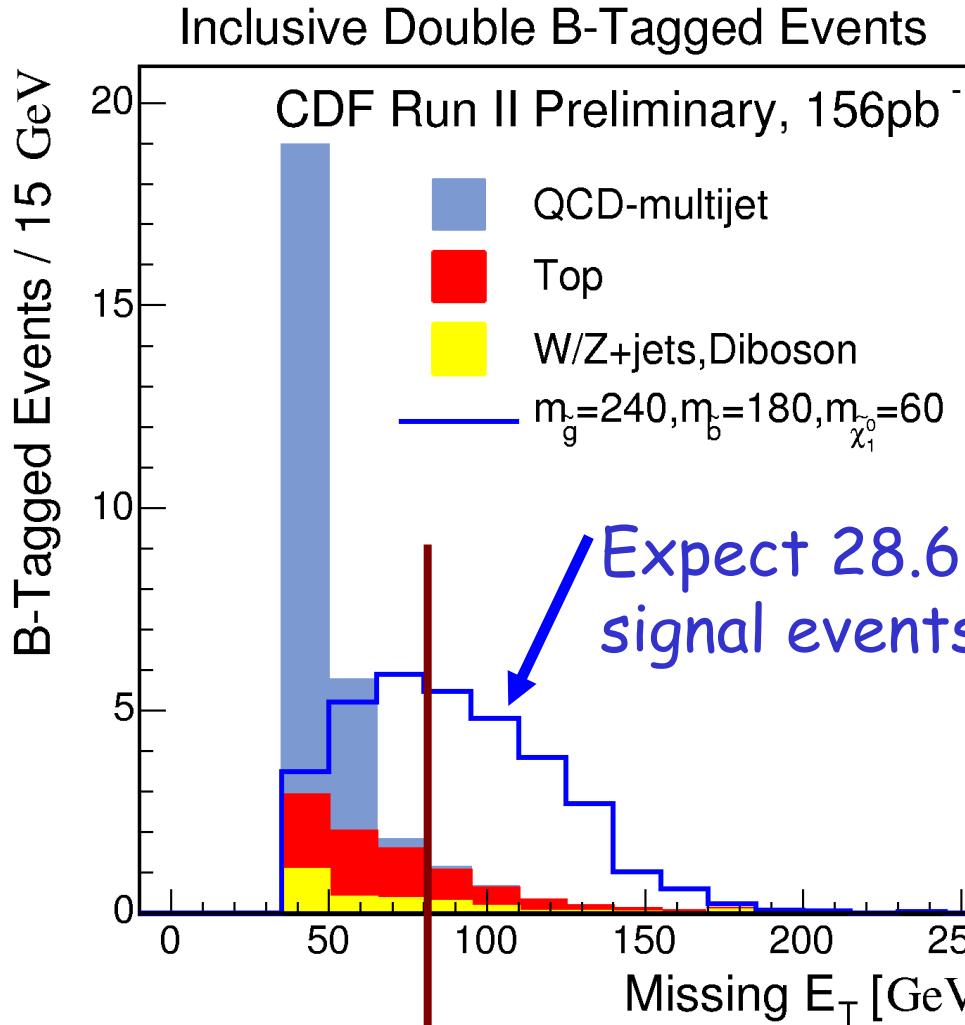
$E_T:$	35-50GeV	35-50GeV	>50GeV
Lepton:	yes	no	yes
W/Z+jets/Diboson	$3.9 \pm 0.8$	$11.0 \pm 1.2$	$9.6 \pm 1.2$
Top	$11.7 \pm 0.2$	$8.2 \pm 0.1$	$35.2 \pm 0.3$
QCD-multijet	$19.2 \pm 4.1$	$129.6 \pm 17.3$	$10.9 \pm 4.5$
Total background	$34.8 \pm 4.2$	$148.8 \pm 17.3$	$55.7 \pm 4.7$
Data	36	121	63

Comparison of standard model background predictions for inclusive single tagged events is in agreement with data

Statistical errors

Dominant systematics:  
 - Tagging efficiency  
 - Energy scale

# Signal Expectations



	Exclusive Single B-Tag	Inclusive Double B-Tag
EWK	$5.66 \pm 0.76 \pm 1.72$	$0.61 \pm 0.21 \pm 0.19$
TOP	$6.18 \pm 0.12 \pm 1.42$	$1.84 \pm 0.06 \pm 0.46$
QCD	$4.57 \pm 1.64 \pm 0.57$	$0.18 \pm 0.08 \pm 0.05$
Predicted	$16.41 \pm 1.81 \pm 3.15$	$2.63 \pm 0.23 \pm 0.66$
Observed	??	??

stat syst

	Acceptance	Expected events
Single Tagged	7.7%	24.3
Double Tagged	9.0%	28.6

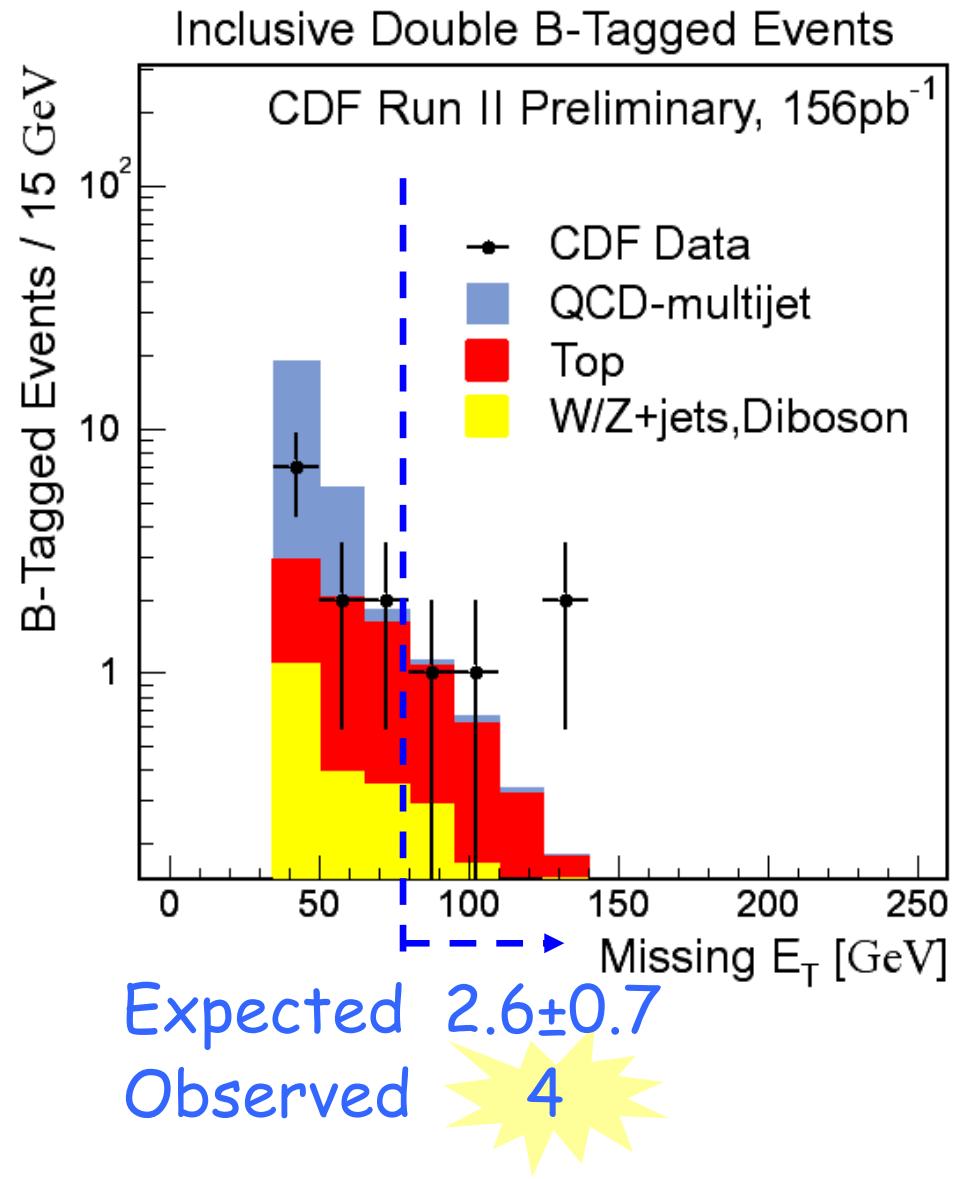
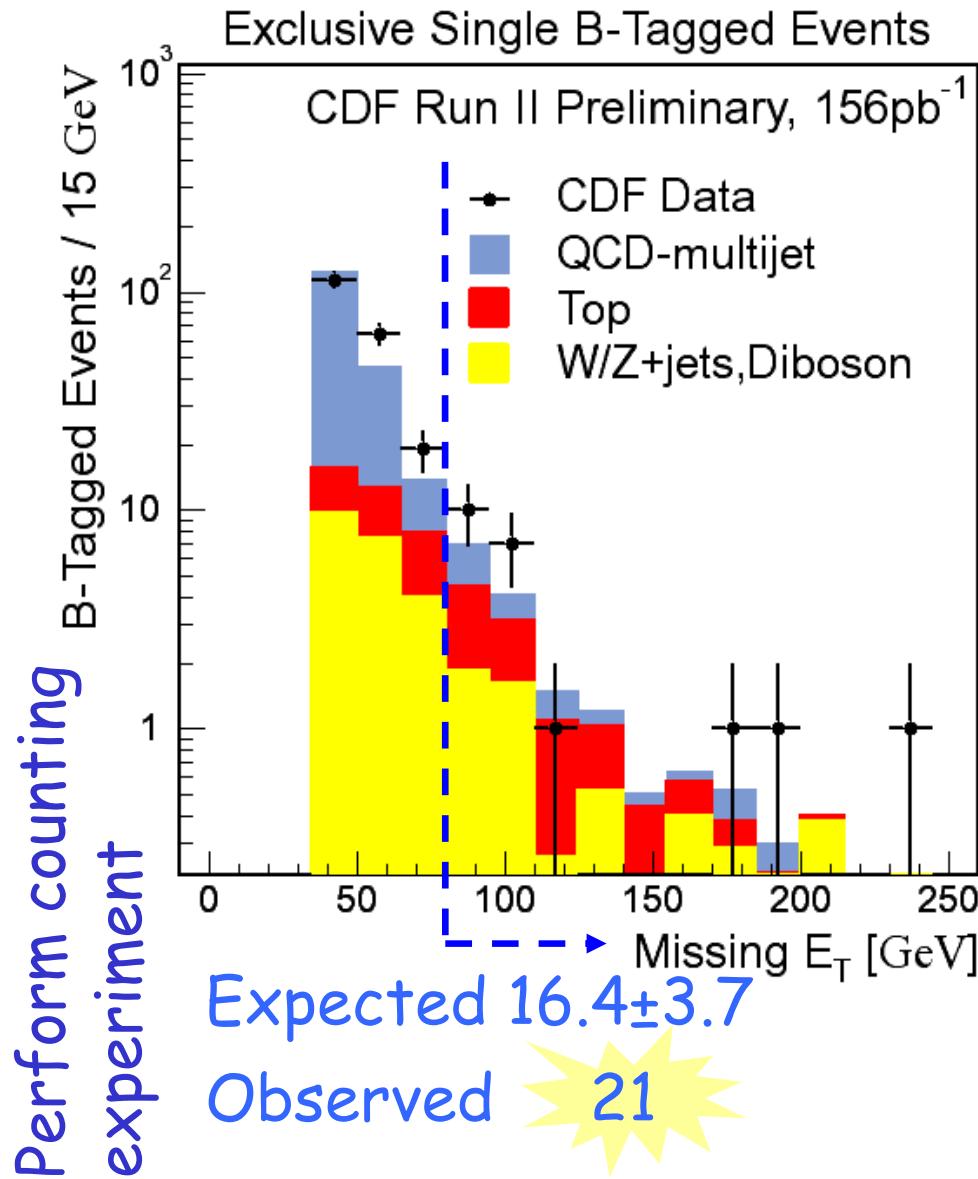
Optimal sensitivity:  $E_T > 80\text{GeV}$

Similar signal acceptance for exclusive single tagged events and inclusive double tagged events

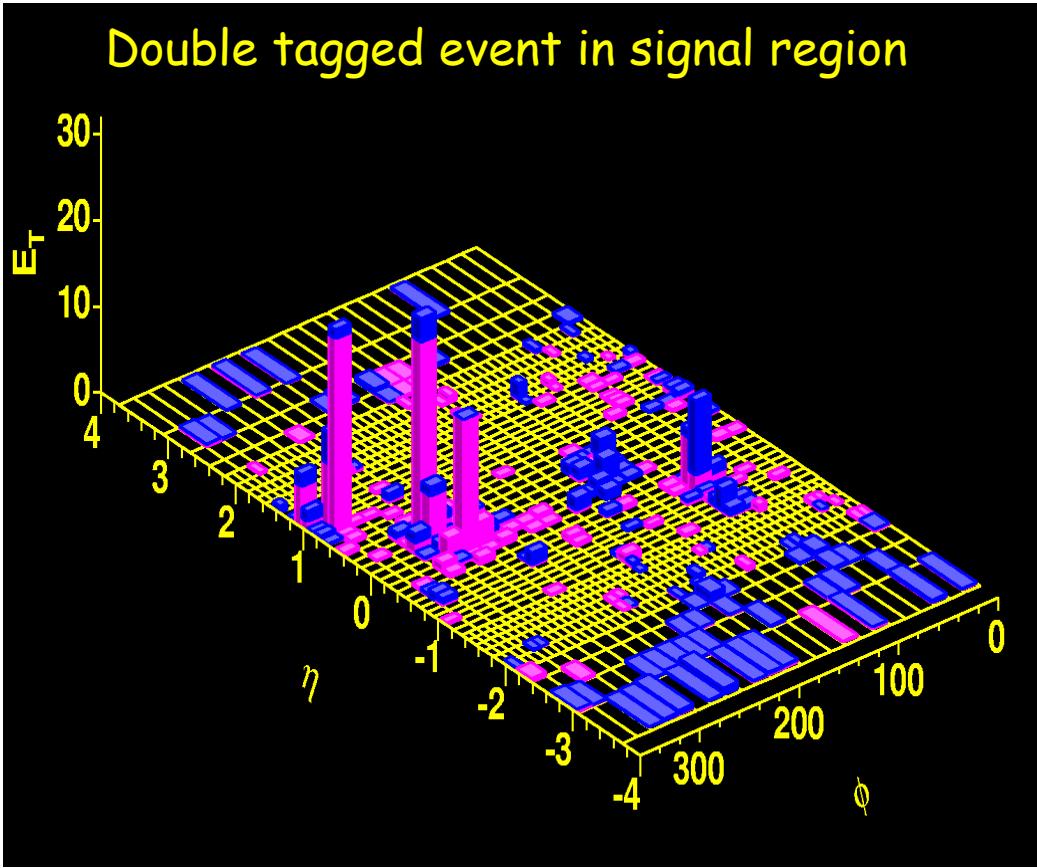
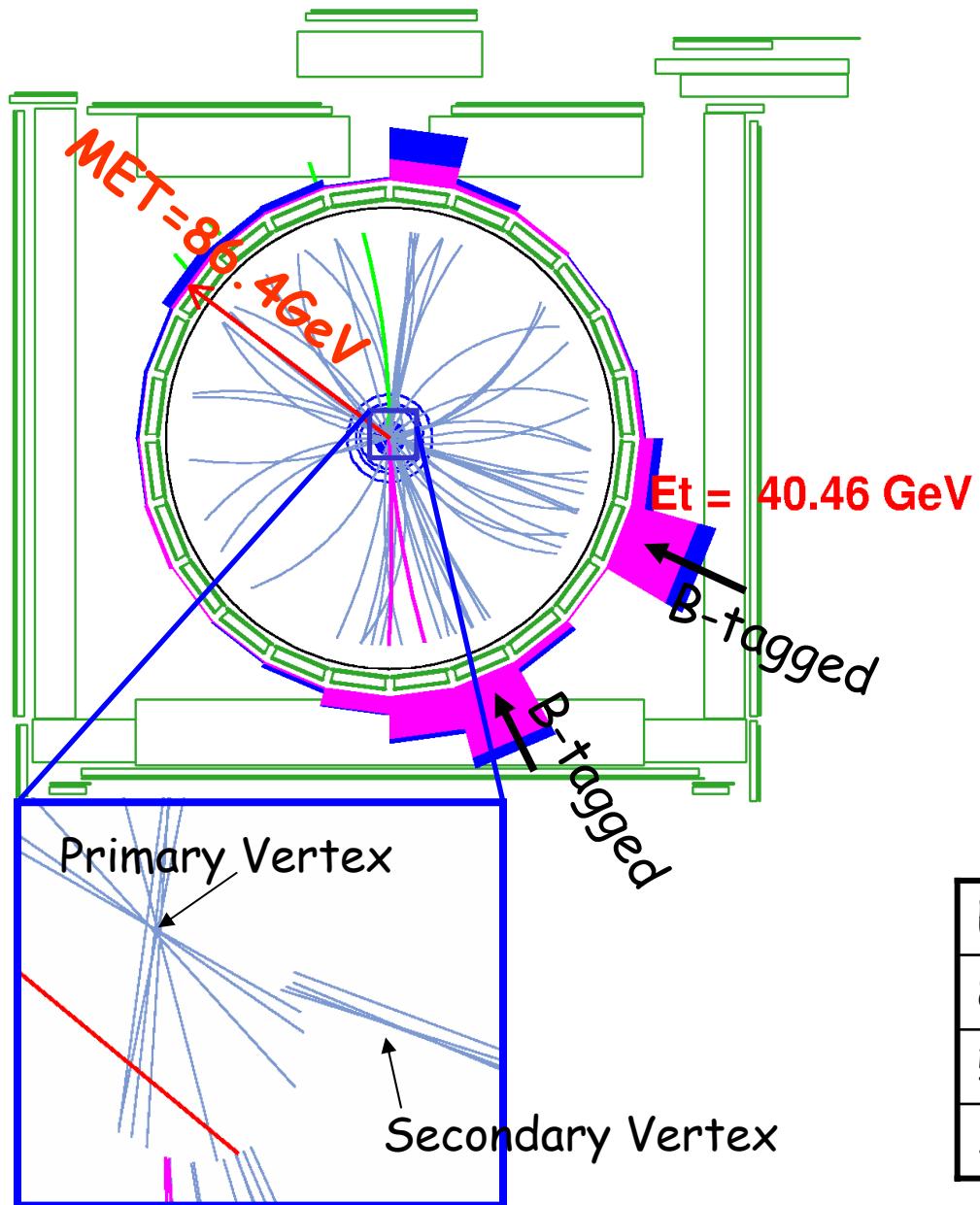
Large signal acceptance  
+ small SM background

# Results

Use  $156\text{pb}^{-1}$  of data taken 2002-2003



# Sbottom Searches

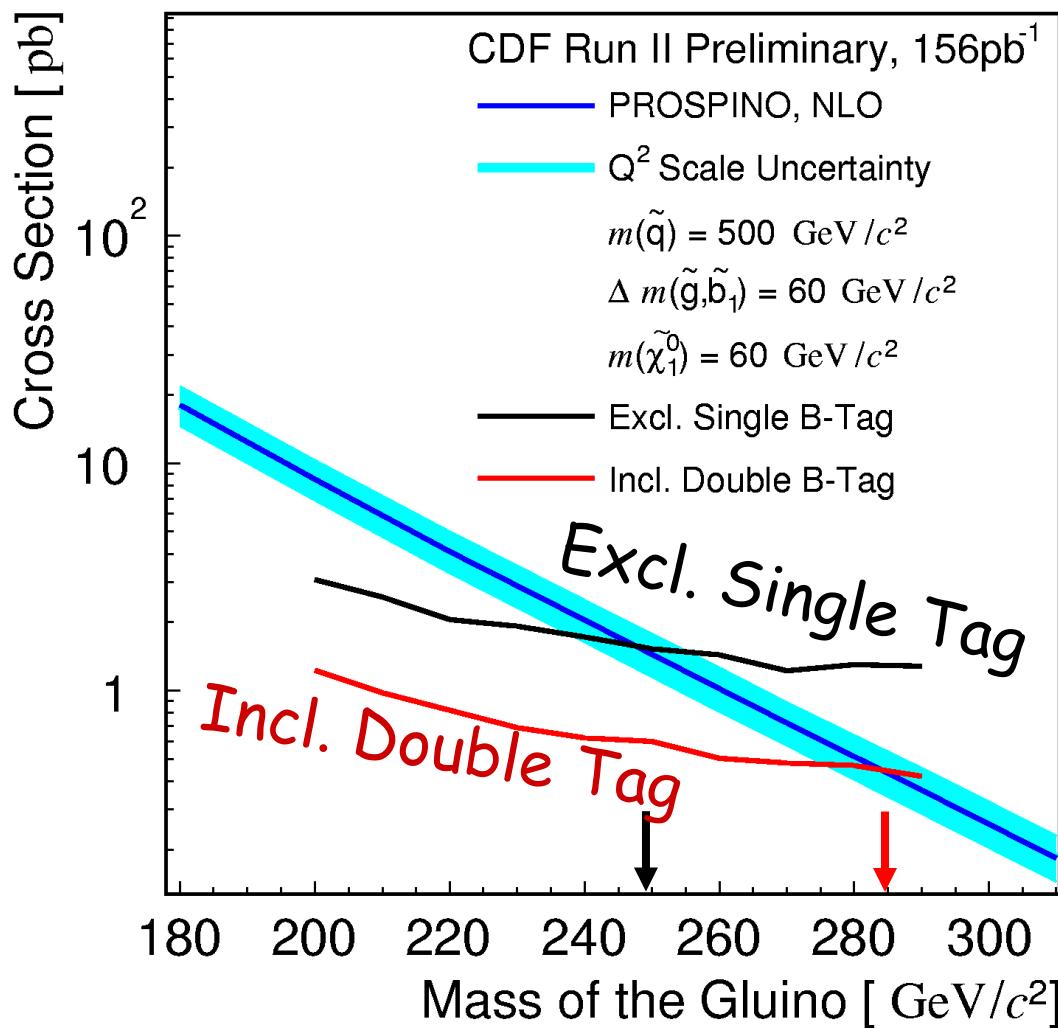


$E_T$	$\eta$	$\phi$	Tag
85.3GeV	0.02	4.99	1
51.6GeV	0.84	5.97	1
30.0GeV	-0.83	1.42	0

# Cross Section Limit

$$\Delta M(\text{gluino}, \text{sbottom}) = 60 \text{ GeV}/c^2$$

Gluino  $\rightarrow \tilde{b}_1 b$ , 95% C.L. Cross Section Limit



Excl. single tag: Exclude 20.6 signal events at 95% C.L.

Incl. double tag: Exclude 8.7 signal events at 95% C.L.

Upper limit on signal events

$$\sigma^{Limit} BR(\tilde{g} \rightarrow \tilde{b}\tilde{b}_1) = \frac{N^{Limit}}{\varepsilon \cdot L}$$

Assume branching ratio 100%

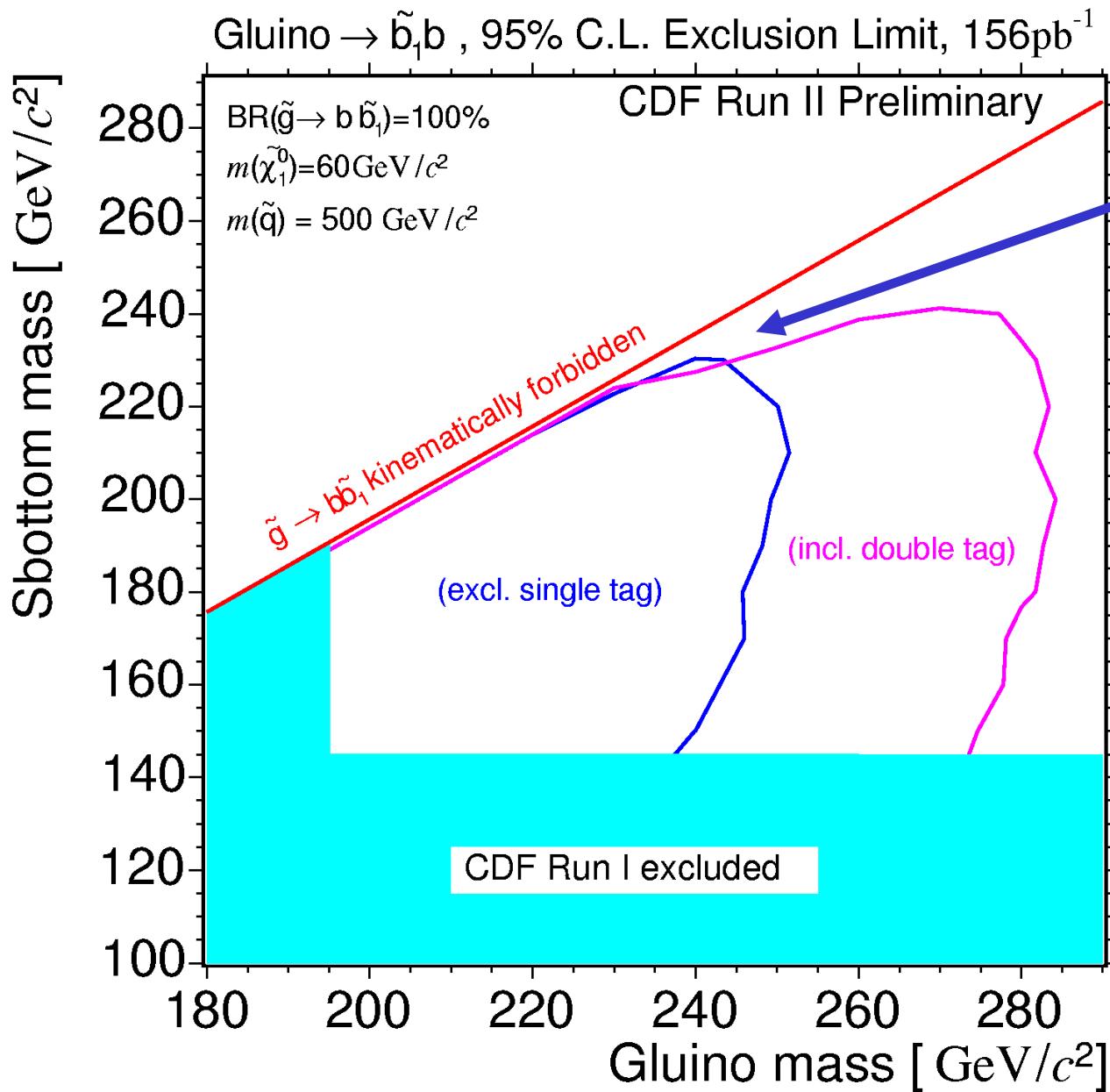
Signal selection efficiency

Luminosity

Now translate upper limit cross section to exclusion plane



# Gluino/Sbottom Exclusion Plane



Exclusive single tag analyses more sensitive for nearly mass degenerated scenario

Exclude new parameter space

Obtain larger exclusion limit using inclusive double tagged events, due to better background suppression by similar signal acceptance

Similar limits expected also for also for larger neutralino mass scenarios

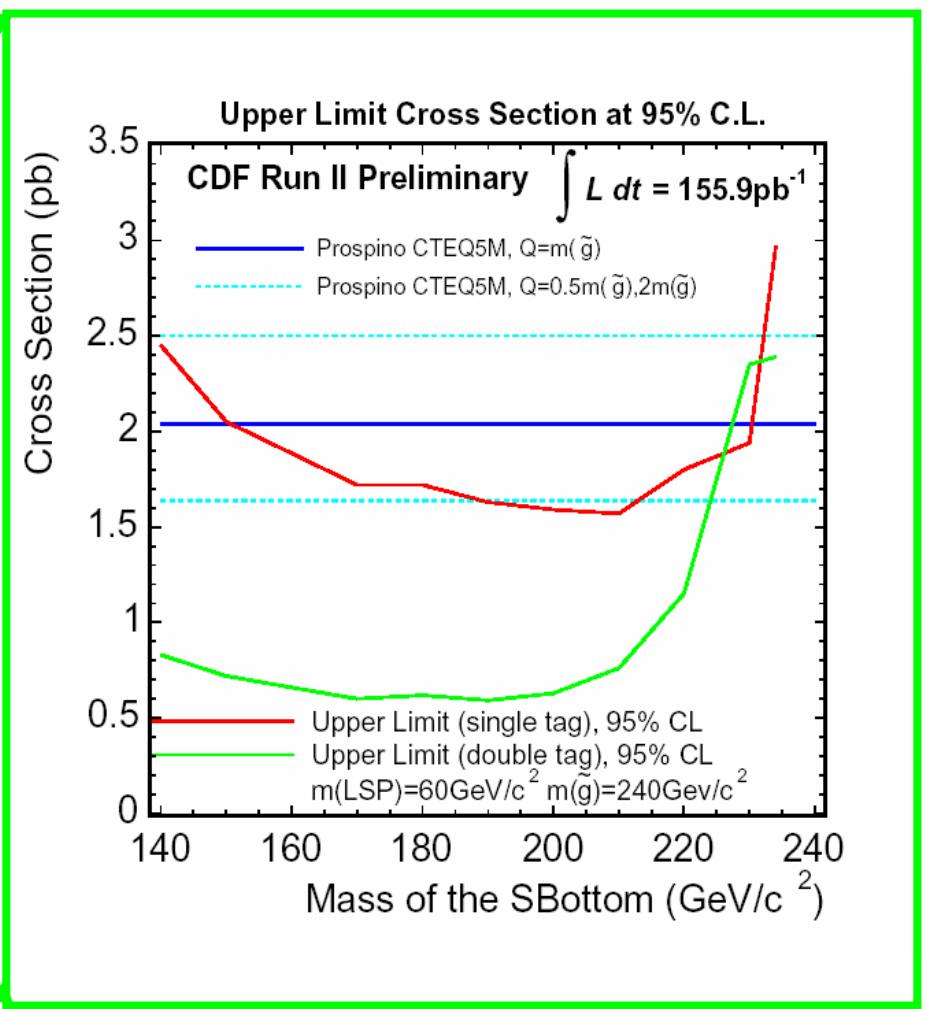
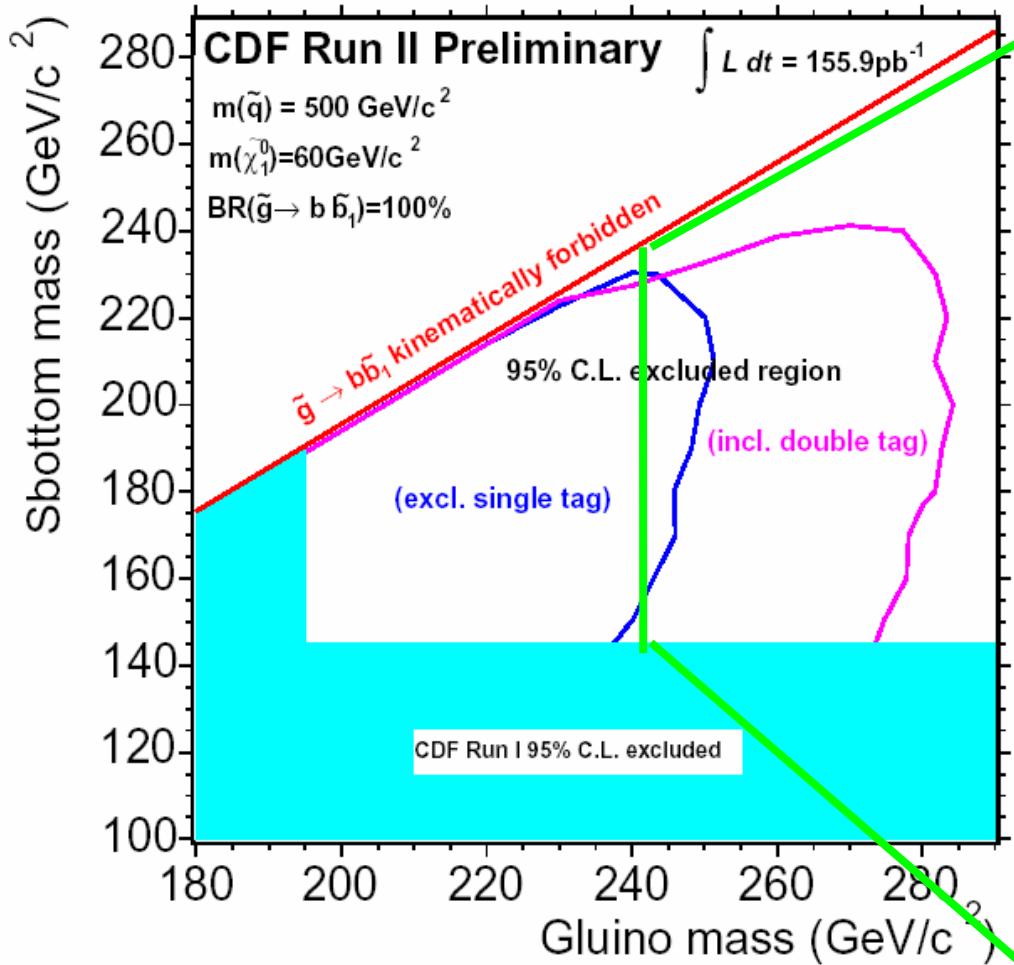


# Conclusions



- Heavy flavor jets and  $E_T$  exciting combination to look for new physics
- Performed search for sbottom quarks from gluino decays
- No excess found and new exclusion limit was set
- Vastly exceed Run I limits
- Searches beyond the standard model are ongoing ...
- [http://www-cdf.fnal.gov/physics/exotic/run2/gluino-sbottom-2003/bless\\_plots.html](http://www-cdf.fnal.gov/physics/exotic/run2/gluino-sbottom-2003/bless_plots.html)

# Gluino/Sbottom Exclusion Plane



**Gluino production allows significant extension of the best limits at high mass Sbottom and low mass neutralinos**



# Signal Acceptance Systematics



Systematic uncertainties have been carefully studied

Systematic Uncertainties	exclusive single tag	inclusive double tag
PDF	2.0%	2.0%
$\Delta\phi$ Cuts	0.5%	0.5%
Lepton Veto	2.0%	2.0%
ISR/FSR	7.5%	5.0%
MC Statistics	3.0%	3.0%
Luminosity	6.0%	6.0%
Vertex Cut	0.5%	0.5%
Trigger Efficiency	2.5%	2.5%
Tagging Efficiency	7.0%	14.0%
Energy Scale	10.0%	10.0%
Total uncertainty	16.5%	19.5%

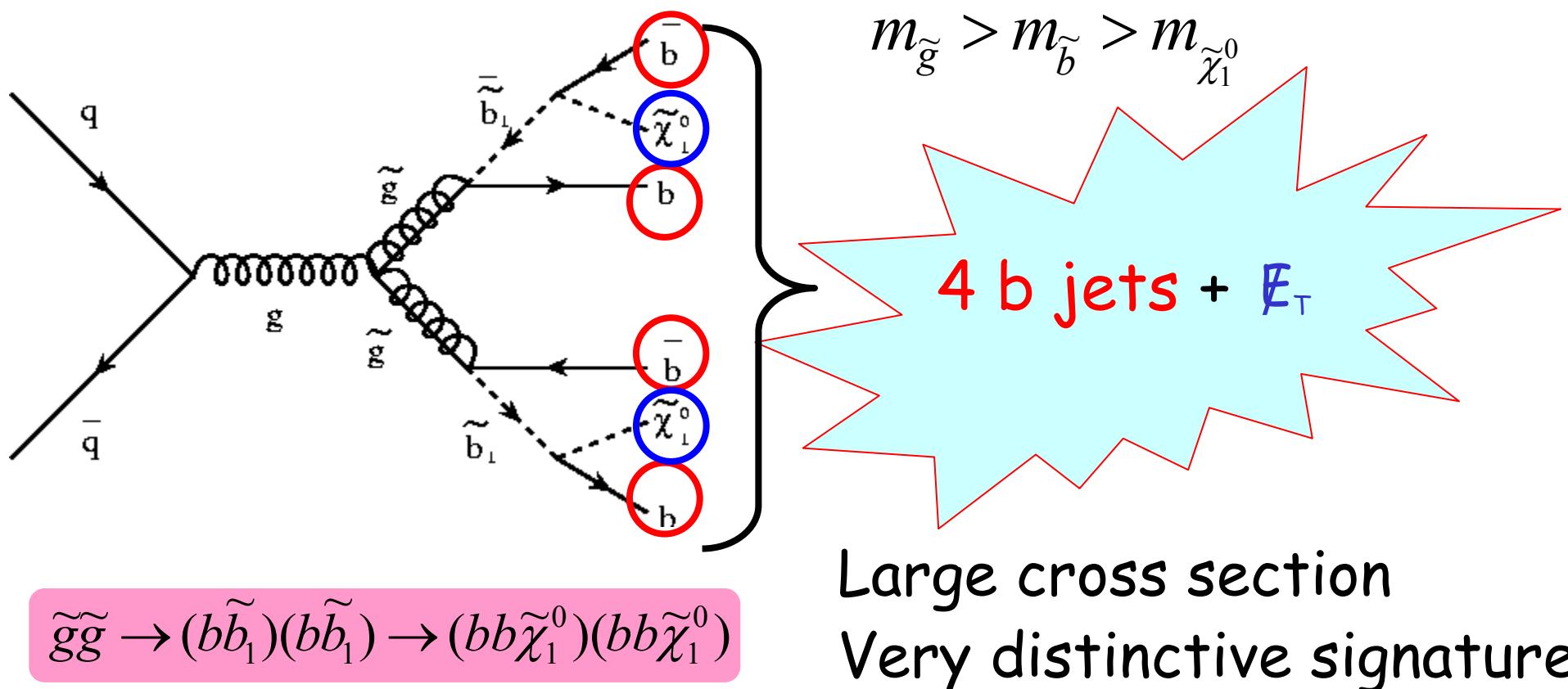
← Increases for mass degenerated scenario

Uncertainty on scale factor for tagging efficiency in data and MC

↔ Dominant systematics

Calorimeter energy correction

Sbottom quarks could be pair produced at the Tevatron or in a scenario where the gluino is heavier than the sbottom, through decays of gluinos. Consider here search for second case, it yields a richer signature



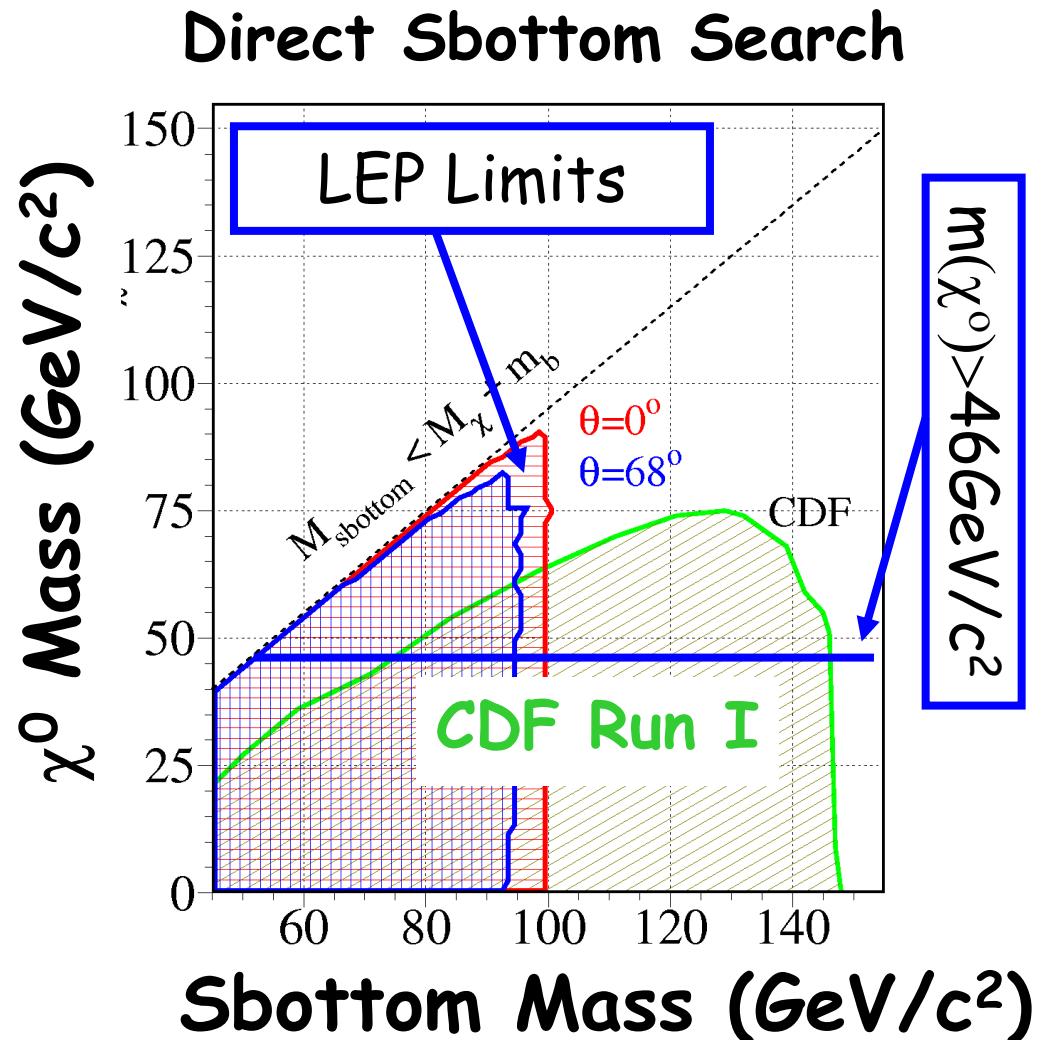
# Sbottom Searches

$$m_{\tilde{b}_{1,2}}^2 = \frac{1}{2}[m_{\tilde{b}_L}^2 + m_{\tilde{b}_R}^2 \mp \sqrt{(m_{\tilde{b}_L}^2 - m_{\tilde{b}_R}^2)^2 + 4m_b^2(A_b - \mu \tan \beta)^2}]$$

$\uparrow$   
Sbottom can be light due to large mass splitting between the eigenstates (large  $\tan\beta$ )

Assume:

- $m_t + m_{\tilde{\chi}_1^+} > m_{\tilde{b}_1} > m_{\tilde{\chi}_1^0}$
- $BR(\tilde{b}_1 \rightarrow b \tilde{\chi}_1^0) = 100\%$
- R-parity conservation which leads to stable undetectable neutralino





# Conclusions



- $E_T$  and B-Tagging well understood
- Used for searches for physics beyond the SM
- Data and background prediction in agreement
- New exclusion limit as function of gluino and sbottom mass found
- Tevatron has the best SUSY discovery potential before LHC
- Direct sbottom search on going
- Continue ambitious searches for SUSY at the Tevatron
- [http://www-cdf.fnal.gov/physics/exotic/run2/gluino-sbottom-2003/bless\\_plots.html](http://www-cdf.fnal.gov/physics/exotic/run2/gluino-sbottom-2003/bless_plots.html)